8

CONTACT METAMORPHISM AT BIG HILL, BENDIGO, VICTORIA

By F. C. Beavis

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Abstract

Thermal metamorphism on the granodiorite contact at Big Hill, S. of Bendigo, is restricted to an aureole less than 1 mile wide. Three zones of metamorphism are recognized: spotted slates, biotite andalusite hornfels, and cordierite hornfels. Selective development of andalusite and apparently restricted development of cordierite in the medium grades are noted. Control of the former is uncertain; the latter is a feature of the retrograde activity which followed the progressive thermal metamorphism.

Introduction

During a study of the structure of the Harcourt-Maldon granodiorite which is still in progress, a small sector of the contact of the massif with Lower Ordovician sediments 7 miles S. of Bendigo was selected for detailed petrological study. In this sector the sediments are slates and greywackes, with a few thin beds of quartzite. The slates are richly fossiliferous, with the Castlemainian graptolite *Isograptus caduceus* var. *victoriae* the typical form.

Thermal metamorphism of the sediments adjacent to the granodiorite is restricted to an aureole generally less than 1 mile in width. The aureole is marked by a sharp asymmetric ridge—the Big Hill Range—with a short steep slope on the S. and a long gentle slope on the N. The crest of the range is 10 to 30 chains from the contact, in medium grade hornfels. The area is drained by Buckeye Creek and its tributaries; the main stream has a course just inside and more or less parallel to the contact. A similar drainage pattern was noted in the SE. of the massif by Hills (1959) who suggested ring fracture control of the intrusion, particularly when the overall arcuate form of the contact is taken into consideration.

The only published work dealing with the contact at Big Hill is a short paper by J. A. Dunn (1921a) in which a quartzite xenolith from the granodiorite was described. The present paper is a petrological study of the contact rocks.

It is desired gratefully to acknowledge the assistance in the field of Adrian Beavis, and the hospitality of Mr and Mrs Dingfelder of Ravenswood. Thanks are due also to Mr V. Biskupsky who made the chemical analyses.

Petrology

Ordovician Sediments

The lithology of the lower Ordovician in the Big Hill area is fairly uniform, with alternating thin beds of slate and greywacke, and occasional quartzites. In the W. part of the area, the carbonaceous graptolite slates become less important than in the east. Dunn (1921b) has described some of the Ordovician sediments from Bendigo, but further description is necessary here.

Slates

The slates are of two types, one somewhat coarser textured than the other. The coarser type shows the development of pale green chlorite along cleavage

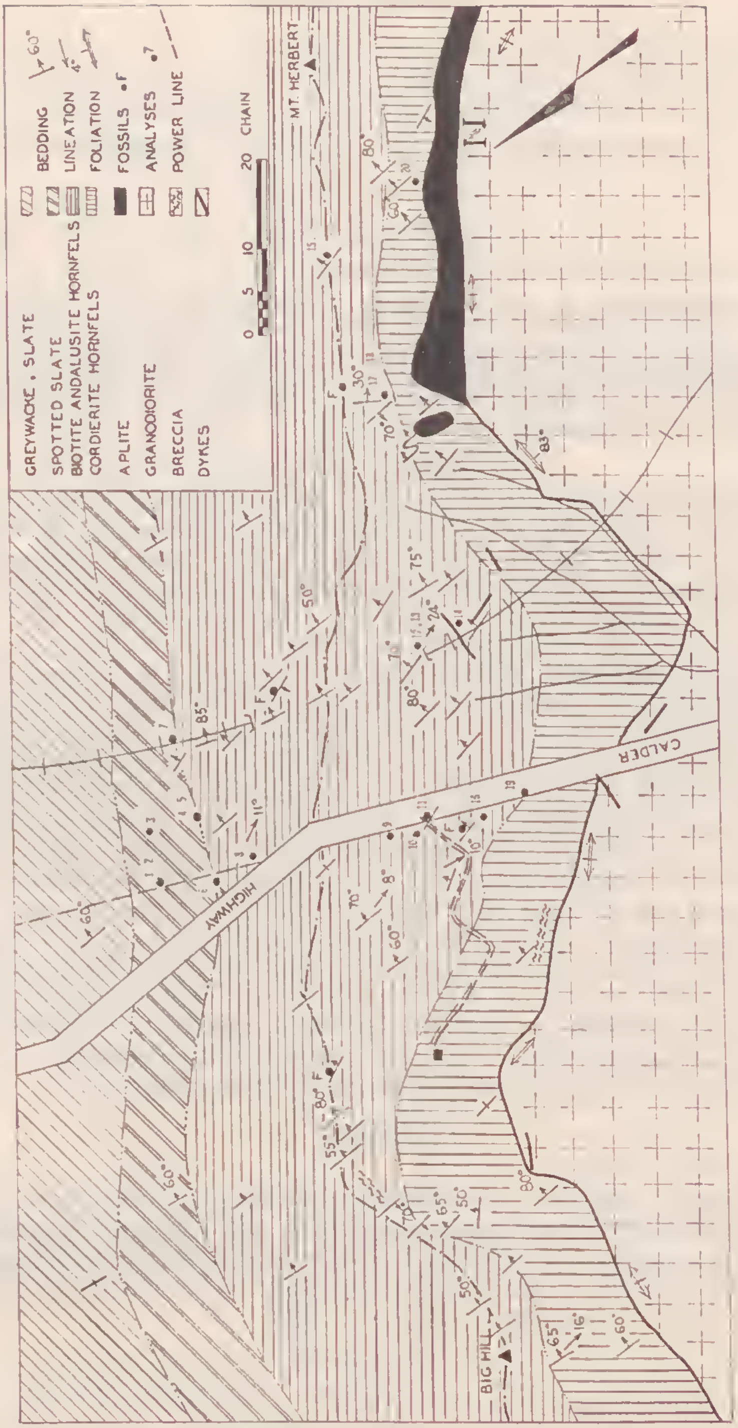
GREYWACKE , SLATE
SPOTTED SLATE
BIOTITE ANDALUSITE HORNFELS
CORDIERITE HORNFELS
APLITE
GRANODIORITE
BRECCIA
DYKES
BEDDING
LINEATION
FOLIATION
FOSSILS
ANALYSES
POWER LINE
0 5 10 20 CHAIN
MT. HERBERT
HIGHWAY
CALDER
BIG HILL

Fig. 1

planes, with sericite abundant throughout the rock. Quartz occurs as minute lath shaped grains, and felspar, a sodic plagioclase, is relatively common. The finer slate has sericite in considerable excess of chlorite, and contains abundant fine black carbonaceous material. Sometimes relatively large flakes of white mica occur along the cleavage planes.

Greywackes

The greywackes are typified by angular to subangular, subequidimensional to elongated sliver-like grains of quartz which show marginal development of authigenic sericite. Some of the quartz grains are dusty with minute black inclusions. These may have a random arrangement, or may form fine parallel trains. Felspar is common, with sodic plagioclase in excess of orthoclase. The felspars are angular but do not form sliver-like laths. Thin flakes of biotite and lesser muscovite occur. The matrix consists of fine sericite and a little chlorite, the latter as blades and shreds, light green in colour. Isolated flakes of chlorite occur with black iron ore about the margins. Some fine quartz and felspar are present in the matrix. The only carbonate present is rare ankerite. Detrital subrounded zircon and tourmaline are frequent.

Quartzites

The pure quartzites are composed almost exclusively of angular to subangular quartz grains, with an outer rim of secondary quartz. Some white mica and small grains of felspar occur rarely; heavy accessories are sometimes abundant with zircon particularly important.

Table 1

Chemical Analyses of Sediments

	1	2
SiO_2	88·32	63·30
Al_2O_3	6·12	15·68
Fe_2O_3	2·00	5·70
FeO	0·94	1·10
TiO_2	0·62	0·79
CaO	0·87	0·95
MgO	0·78	3·15
Na_2O	1·48	1·79
K_2O	1·25	3·07
H_2O+	1·78	3·60
H_2O-	0·32	0·61
Total	99·48	99·74

1 Greywacke, Crusoe Reservoir, Kangaroo Flat
2 Slate, Crusoe Reservoir, Kangaroo Flat

Analyses: V. Biskupsky

Intrusive Rocks

Granodiorite

The granodiorite in the contact area shows little variation from that further S. at Harcourt (cf. Summers 1914, Baker 1942). Locally, on the contact, a type of rapikivi texture may be noted, with ovoid phenocrysts of orthoclase, 1 cm in diameter, rimmed with oligoclase, and set in a matrix of oligoclase, quartz and biotite. Generally, however, the texture is normal, hypidiomorphic, with maximum crystal size 3 mm. Quartz is abundant, and is invariably anhedral. Oligoclase-andesine may be slightly in excess of orthoclase (1·3 : 1—1 : 1). The oligoclase-andesine is euhedral to subhedral, and is usually zoned, with the cores more calcic, and sometimes kaolinized. The cores may be strongly poikilitic, with small inclusions of zircon and apatite. The biotite is of two types: one pale green-brown and strongly pleochroic, the other, dark brown, almost opaque. This latter type is absent some distance in from the contact. Apatite, zircon, rutile, ilmenite, sphene, cordierite and muscovite are accessory.

Dykes of granodiorite which intrude the metamorphic rocks have a coarser texture than the rock of the main massif, with crystals up to 5 mm long. Quartz occurs as large anhedral pools, but some smaller euhedral quartz crystals may be enclosed in the large poikilitic plagioclase crystals. The plagioclase is sodic andesine, and is frequently kaolinized. The orthoclase, which is subordinate to the plagioclase, shows little or no alteration. In almost all cases, the biotite has been metasomatically replaced by clinozoisite.

Aplite

The aplite of the Mt Herbert dyke has a fine (0·7 mm) saccharoidal texture. Dark minerals are rare; a few fine flakes of chloritized biotite and some secondary clinozoisite were noted. Quartz and felspar are the main constituents. The quartz invariably is anhedral. Orthoclase is in excess of oligoclase-andesine, which sometimes shows micrographic intergrowth with the quartz.

Other aplite dykes observed were frequently too weathered for examination. Two studied in thin section were identical in texture and composition with the aplite of the Mt Herbert dyke.

Table 2

Analyses of Intrusive Rocks

	1	2	3
SiO_2	70·94	70·65	76·22
Al_2O_3	13·99	12·54	11·66
Fe_2O_3	0·35	0·52	0·99
FeO	3·02	3·59	0·11
TiO_2	0·58	0·46	0·24
CaO	2·35	2·11	0·59
MgO	0·80	0·85	0·34
Na_2O	3·94	3·01	2·72
K_2O	3·66	4·15	5·22
H_2O+	0·32	0·76	1·34
Total	99·95	98·64	99·43

1 Granodiorite, Harcourt (H. S. Summers 1914)
2 Granodiorite, Calder Highway, Big Hill (V. Biskupsky)
3 Aplite, Mt Herbert (V. Biskupsky)

Metamorphic Rocks

Three distinct zones of metamorphism have been mapped in the Big Hill aureole by the writer. The lowest grade of metamorphism is represented by spotted slates, a narrow zone at the outer margin of the aureole. These slates pass into rocks which, while still spotted, are typified by the development of relatively large flakes of biotite and porphyroblasts of andalusite, with sericite-cordierite aggregates generally present. The highest grade of metamorphism is represented by the zone of cordierite hornfels, from which andalusite is absent; large porphyroblasts of cordierite are characteristic.

Within the aureole, two features are particularly noteworthy. Except locally, the rocks have a foliated rather than a hornfelsic texture and would be described best as phyllites and semi-hornfelses rather than hornfelses. This is probably the result of the mimetic emphasis of the axial plane cleavage of the pelites. The second feature is the limited degree of recrystallization which has occurred in the low and medium grade rocks. This is illustrated by the preservation of readily identifiable fossils in high grade andalusite-biotite hornfels in which varietal determination of graptolites was possible to within less than 10 chains of the contact.

Spotting is typical of all but the highest grades of the metamorphic rocks and is a macro-feature of the retrograde activity. Although in thin section the nature of the spots is seen to change (Fig. 2) ; this change is frequently not apparent in the hand specimen.

Zone of Spotted Slates

The pelitic rocks of this zone have typically ovoid spots which are aggregates of pale green sericite and lesser chlorite, associated with which may be large poikiloblasts of muscovite. The matrix of the rock is composed of sericite, a little chlorite, fine quartz and sodic plagioclase (? albite), fine graphite and some magnetite.

In the metagreywackes the larger quartz grains are more rounded than in the normal rock, suggesting some marginal solution; some of the quartz grains contain fine needles of an indeterminate mineral. A few grains of sodic oligoclase are present. The matrix shows appreciable recrystallization and consists of fine muscovite, very rare biotite, quartz and felspar, with sericite abundant. Detrital zircon and tourmaline are relatively common.

In the narrow belt of transition from this zone to that of biotite andalusite hornfels, the metagreywackes show no significant changes. The pelitic rocks, however, do show a more advanced metamorphism, and for the first time there is mineralogical expression of possibly initial compositional differences. Samples taken from adjacent beds may be used to illustrate this point. In one type (Analysis 5, Table 3), the spots, which have irregular outline, consist of fine sericite with minute crystals of cordierite and relatively large flakes of muscovite. The matrix is essentially sericitic with a little fine quartz. Graphite is very rare. In the sample from the adjacent bed (Analysis 4, Table 3) the matrix is similar except that graphite is abundant. The spots, though irregular, are less so than in the first specimen. They may be uniform in composition, when they consist of pale green isotropic material, or they may be zoned, with a core of cordierite or, more commonly, andalusite, surrounded by brown isotropic material and an outer rim of sericite. Associated with the spots are euhedral porphyroblasts of andalusite, usually with a spongy core rich in graphite, pale green mica and sericite, which may also occur about the margins. Almost invariably a rim of graphite occurs on the andalusite porphyroblasts. Rarely, the typical chiastolite cross is present (Fig. 2 (vi)).

Zone of Biotite-Andalusite Hornfels

More or less pure metaquartzites were observed only rarely in this zone; the best exposure noted was on the Calder Highway, near the Big Hill cutting. The metaquartzite has a mosaic texture. The quartz contains fine black inclusions

Fig. 2

as well as fine needles. There are a few crystals of sodic plagioclase. Any intergranular matrix present has been partially recrystallized, and whilst dominantly sericitic, flakes of muscovite and of pale brown, strongly pleochroic biotite are relatively abundant. A little cordierite may be present, with accessory zircon, tourmaline, apatite and magnetite.

The metagreywackes show a marked reduction in felspar, which is a sodic plagioclase. Biotite, occurring as small strongly pleochroic flakes, is abundant. Cordierite is rarely present. Near the S. portal of the Big Hill Tunnel, a variety of metagreywackes occurs. The larger crystals of the more arenaceous types are exclusively quartz. The matrix is sericite. The more pelitic greywackes show strong development of muscovite in the matrix. These rocks are spotted, with the spots composed of sericite, with minute crystals of cordierite and relatively large flakes of muscovite on the margins of the spots.

The pelitic rocks show some more or less consistent changes across this zone. Near the N. portal of the tunnel the rocks are spotted: the spots are sericite-cordierite aggregates up to 1·5 mm long, frequently with cores of cordierite. Relatively large flakes of muscovite are present both in the spots and in the matrix. The muscovite has a poikiloblastic habit, with small inclusions of cordierite. Sericite, quartz and muscovite constitute the matrix. Near this rock, a similar type occurs except that muscovite and cordierite are reduced, and biotite becomes important. On the crest of the ridge above the tunnel, alteration is more advanced. Here, two distinct types of hornfels were recognized. One type has weakly developed spots of sericite with small cordierite crystals and well-formed flakes of muscovite. Some of the spots have a crude zonal structure, with graphite rich cores. The matrix is composed of quartz, rare felspar, sericite and graphite. This rock is of interest since it is unusual for graphitic pelites in this zone to contain no andalusite. The other type has well developed graphitic spots, which have cores of cordierite and an outer zone of sericite. Some large flakes of muscovite occur in the spots. Anhedral cordierite with inclusions of fine graphite is present while anhedral to subhedral porphyroblasts of andalusite are abundant. Some of the andalusite shows replacement along margins and cleavage planes by a pale green fibrous ? chloritic material.

Near the centre of the zone, the typical biotite andalusite hornfels reaches the peak of its development. The rocks are spotted; the spots, 2 mm long, have irregular outlines, and are sericitic with fine inclusions of cordierite, and trains of graphite. Subhedral to euhedral porphyroblasts of andalusite are abundant. Some have spongy cores enclosing fine flakes of biotite (Fig. 2 (iv)). Sometimes the andalusite, though abundant, occurs as very small euhedra.

On the spurs rising from the contact to Mt Herbert, rocks transitional to the cordierite hornfels zone are exposed. Spotting is still typical, but the spots consist of small flakes of muscovite and have graphite rich cores. Euhedral andalusite is almost completely replaced by green ? chloritic material. Replacement has sometimes been from the outer margins and sometimes from the cores (Fig. 2 (vii)). The matrix is rich in fine muscovite, lesser biotite, fine quartz and graphite.

Zone of Cordierite Hornfels

The development of definite porphyroblasts of cordierite and biotite and the complete absence of andalusite are typical of rocks of this zone, which tend more to the true hornfelsic rather than foliated textures. Locally, true hornfelsic texture is fully developed.

A series of metaquartzites from the contact illustrates the highest grade of metamorphism of the pure arenites. One type, from 10 chains W. of the railway line consists of a mosaic of anhedral quartz with fine flakes of biotite developed about the margins of each crystal (Fig. 2 (x)). The quartz has abundant fine black inclusions which have a more or less random distribution. A similar type from the contact with the aplite dyke shows the quartz crystals in direct contact with each other, with sutured margins. A metaquartzite adjacent to this is notable for the development of superindividuals (Fig. 2 (viii)). These are large (4-8 mm) crystals with small inclusions of zircon and biotite and fine black inclusions forming a pattern suggesting that these define the pre-recrystallization margins of smaller crystals. Optical continuity exists throughout large individuals. In all of these rocks, any pelitic matrix has been recrystallized and consists of biotite, muscovite and cordierite.

The metagreywackes of this zone show advanced recrystallization of both the large grains and the matrix. Except in the very highest grades, there is still a tendency to spotting. The spots are 1·5 mm long and most are composed of an indeterminate cryptocrystalline to glassy material. Some, however, are sericitic with well developed flakes of muscovite. They may have rims of cordierite. The large quartz grains are well rounded. Some orthoclase is present. The matrix of the rock contains anhedral porphyroblasts of cordierite, muscovite, green biotite and minute felspars.

In the pelites, spots are generally but not invariably absent. Subhedral to anhedral porphyroblasts of cordierite are abundant, all of which, in specimens adjoining the contact, have been pinitized. Large flakes of muscovite are common, but biotite is rare. The abundance of secondary tourmaline in some of the rocks suggest that pinitization of the cordierite may have been due to pneumatolytic activity. Somewhat closer to the contact the rocks have elliptical concentrations of poikiloblastic cordierite, with fine inclusions at the cores. Surrounding these poikiloblasts are flakes of biotite and large flakes of muscovite which otherwise is not common.

A specimen from Big Hill is one of the few true hornfelses observed. The rock is dominated by irregular elliptical poikiloblasts of cordierite. Included in the cordierite are small flakes of pale, strongly pleochroic biotite, needles of ilmenite and rare tourmaline. Biotite frequently surrounds the cordierite; pale yellow cordierite, showing polysynthetic twinning may be associated with the biotite. The matrix of the rock is composed of cordierite, biotite and quartz. A series of hornfelses from the contact at Mt Herbert contain elliptical aggregates of muscovite with cores of cordierite. The matrix consists of cordierite, muscovite, green biotite, quartz and rare felspar.

An unusual type from the contact at Big Hill homestead is essentially a green biotite-muscovite-sericite rock. Muscovite occurs as large poikiloblastic flakes, with minute inclusions of cordierite. These sometimes occur as elliptical aggregates intimately associated with cordierite poilkiloblasts, the whole surrounded by a rim of chlorite. Sheaves of green biotite are abundant, while white tremolite occurs in significant proportions.

Xenoliths

Xenoliths are rare on the Big Hill contact. The most important is that described by Dunn (1921a). A few small arenaceous types were also observed near Big Hill.

TABLE 3

Chemical Analyses of Metamorphic Rocks

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SiO_2	89·50	79·89	86·13	69·58	64·45	54·25	70·85	67·80	72·52	85·98	63·95	66·38	60·55	62·59	68·89	61·25	64·75	60·33	68·49	98·67
Al_2O_3	4·78	8·68	3·99	12·68	16·92	23·34	13·86	14·45	13·35	5·85	20·10	15·15	19·10	15·63	18·65	23·48	16·25	15·45	15·05	0·88
Fe_2O_3	1·01	1·88	3·81	4·61	4·49	5·70	3·04	4·89	3·01	1·91	2·09	4·42	4·80	6·40	1·26	2·04	4·12	12·02	4·01	0·09
FeO	0·49	1·04	1·00	0·34	0·24	1·10	0·26	0·83	0·66	0·08	0·71	0·44	0·64	0·50	0·26	0·36	1·24	0·64	0·35	—
TiO_2	0·41	0·47	0·61	0·55	0·58	0·95	0·54	0·74	0·41	0·20	0·40	0·59	0·60	0·83	0·54	0·61	0·59	0·12	0·43	0·47
CaO	0·65	0·65	0·75	0·50	0·41	0·60	0·56	0·74	0·41	0·61	0·59	0·54	0·65	0·52	0·56	0·37	0·52	0·27	0·49	0·37
MgO	0·20	0·42	0·41	0·38	0·25	3·19	0·65	1·43	0·69	0·30	—	0·53	0·98	0·73	0·32	0·63	0·82	0·80	0·84	—
Na_2O	0·98	0·95	0·64	0·81	0·61	0·65	0·51	0·64	0·86	1·83	0·53	0·46	1·00	1·45	0·51	1·09	0·80	0·80	0·55	0·10
K_2O	0·91	2·20	0·89	4·20	4·85	3·75	4·29	2·96	3·23	0·83	3·15	4·23	4·80	4·86	4·65	3·41	4·65	4·29	3·21	0·12
C	—	—	tr.	1·10	0·10	1·80	0·80	—	0·57	—	0·40	1·00	—	—	tr.	—	tr.	tr.	0·54	—
H_2O+	1·21	2·76	2·18	4·90	6·48	4·18	4·10	4·58	3·23	1·42	7·25	5·15	5·40	4·98	4·76	5·05	4·38	5·48	5·27	0·30
Total	100·14	98·94	100·41	99·65	99·38	99·51	99·38	99·06	98·94	99·01	99·17	98·86	98·52	98·49	100·40	98·29	98·12	100·77	99·23	100·33

Analyses: V. Biskupsky

Zone of Spotted Slate:

1 Metaquartzite
2 Quartz—felspar—sericite metagreywacke
3 Quartz—muscovite—sericite—(graphite) metagreywacke

Transitional between Zone of Spotted Slate and Zone of Biotite—Andalusite Hornfels:

4 Spotted andalusite—sericite—graphite—(cordierite) hornfels
5 Sheared quartz—sericite—muscovite hornfels
6 Quartz—andalusite—cordierite—sericite—biotite—graphite hornfels.
7 Quartz—biotite—sericite—andalusite—graphite hornfels.

Zone of Biotite-Andalusite Hornfels:

8 Quartz—biotite—(cordierite) metagreywacke
9 Quartz—biotite—andalusite—graphite—(cordierite) hornfels
10 Quartz—biotite—muscovite—sericite metagreywacke
11 Spotted chlorite—sericite—andalusite—graphite hornfels
12 Biotite—andalusite—graphite hornfels
13 Quartz—sericite—muscovite—(andalusite) hornfels
14 Quartz—sericite—muscovite—cordierite metagreywacke
15 Spotted sericite—andalusite—graphite—quartz hornfels
16 Quartz—biotite—(cordierite) hornfels
17 Quartz—sericite—muscovite—andalusite hornfels
18 Quartz—muscovite—sericite—chlorite hornfels

Transitional between Zone of Biotite-Andalusite Hornfels and Zone of Cordierite Hornfels:

19 Quartz—muscovite—biotite—sericite—cordierite hornfels

Zone of Cordierite Hornfels:

20 Metaquartzite

For localities of analysed specimens, see Fig. 1.

The xenoliths consist of a fine mosaic of quartz with some rare andesine and rarer orthoclase. Biotite is relatively abundant about the margins of the quartz. This is usually pale brown and strongly pleochroic. Cordierite is absent. Fine needles of sillimanite occur; these are frequently, but not invariably, enclosed in the quartz.

Discussion

The mineral assemblages of the metamorphic rocks are shown on Table 4. The true nature of the original parent rocks is uncertain since these had been raised to the 'Chlorite Zone' during folding which predated the thermal metamorphism.

TABLE 4
Mineral Assemblages of Metamorphic Rocks

Mineral	Parent Rock	Spotted Slate	Biotite-Andalusite Hornfels	Cordierite Hornfels	Xenoliths
Quartz	....	....	....	....	....
Plagioclase	....	......		......	....
Orthoclase				......	....
Sericite	....	....	....	... .	......
Chlorite	....	....	....	... .	
Muscovite	....	....	....	....	....
Green Biotite	....	....	......	....	......
Brown Biotite			....	....	....
Andalusite		......	....		
Cordierite		(......	........)...	....	
Graphite	....	....	....	......	
Tremolite				......	
Sillimanite					....

Consideration of both the chemical composition and mineral assemblages of the rocks indicates immediately that, in spite of varying mineralogy, chemical compositions of both the pelitic rocks and greywackes are constant across the aureole. The association of graphite with andalusite and the restricted development of the latter mineral may be noted also. Generally, within the zone of biotite andalusite hornfels, the andalusite occurs as large cores to the ovoid spots or as euhedral porphyroblasts; occasionally it is present as very fine crystals disseminated throughout the rock (as, e.g. in the hornfels of analysis 6).

The examination of analyses 4 and 5, 12 and 13, and 17 and 18 suggested initially that some chemical difference might account for the selective development of andalusite since, for each of these pairs, from adjoining beds, and therefore subject to the same metamorphic conditions, one member contained andalusite, while this was absent from the other. In one case (analysis 5) the effect may have been due to localized shearing, and in another (18) metasomatism had occurred, so these comparison were not valid. Pitcher and Read (1960) have suggested that, while andalusite is typically the low temperature silicate, it might develop only in rocks of special composition, i.e. pelites rich in FeMg relative to available aluminium, where possibly the concentration of the divalent ion in, say, biotite, may influence the growth of a particular aluminium silicate. Pitcher and Sinha (1958) showed that in the Ardara aureole, rocks with abundant andalusite are relatively richer in magnesia.

Table 5 shows the mean compositions of the metapelites from the zone of biotite andalusite hornfels in the Big Hill auerole.

TABLE 5

	A	B
SiO_2	65·73	62·15
Al_2O_3	17·05	17·87
Fe_2O_3	3·67	6·23
FeO	0·62	0·43
TiO_2	0·59	0·53
CaO	0·54	0·39
MgO	0·84	0·60
Na_2O	0·68	0·98
K_2O	4·10	4·35
C	0·63	—
H_2O+	4·81	5·49

A Andalusite hornfels; B Hornfelses containing no andalusite.

The application of tests showed that the statistically signifieant differenees are the higher Fe_2O_3 and H_2O+ content of the andalusite-free hornfelses, and the presence of C in the andalusite hornfelses. The higher proportion of MgO in the andalusite hornfelses is of only minor statistical signifieance. Thus there is no definite support for the ideas of Pitcher and his co-workers in the Big Hill aureole. While the andalusite hornfelses usually contain graphite, this is not always so; it is unlikely in any ease that graphite would have any active role in metamorphic reactions whieh produced andalusite, and it is probable that the association is due to the original depositional environment.

The persistenee of muscovite throughout the aureole is to be expected in rocks in whieh serieite is in excess of chlorite (Tilley 1926); this is reflected in the consistently high K_2O content. Similarly, though cordierite persists from the medium grade hornfelses, the weak development of this mineral is due, in part, to the potassic nature of the sediments. Compton (1960) found that in aureoles in the Santa Rosa Range, Nevada, eordierite and andalusite were invariably found together in the metapelites. This is not true of the Big Hill aureole, where, in medium grades, eordierite may occur without andalusite, and in the high grades, from which andalusite is always absent.

In the high grade hornfels, the serieitization of the cordierite is clearly retrograde, and at the contact the replacement of eordierite by muscovite and green biotite is evidence of retrograde metasomatism. In both the medium and high grades, the abundance of spots is also maero evidence for retrograde activity. In the lower parts of the biotite andalusite hornfels zone it is often difficult to assess whether the association of cordierite with ovoid spots of sericite is due to some retrograde reaction or whether it is progressive. Higher in this zone, as well as in the zone of eordierite hornfels, the association is eertainly retrograde. The assemblage andalusite-museovite-biotite appears to be stable in the middle zone and it is almost certain that the cordierite present was involved in the retrograde reaction:

Cordierite + muscovite → biotite + andalusite + quartz.

Metasomatism has played only a minor role in the metamorphism, exeept immediately adjacent to the eontaet. It is clear, however, that water was important because of the large size of the biotite, muscovite and andalusite crystals, the water content of the roek (mueh higher than in the unaltered sediments) and the generally very high Fe_2O_3/FeO ratios. Other aspects on which comment is necessary are firstly, the presence of tremolite in one contact hornfels, due to at least one pelitic bed being richer in lime than the majority; secondly, the abnormally high (12%) Fe_2O_3 content of the rock of analysis 18. This rock has a more or less normal mineralogy—quartz, rare felspar, sericite, but chlorite is more important than usual and fine hematite is disseminated abundantly throughout the rock, indicating local iron metasomatism close to this part of the contact.

Comparison of the Big Hill aureole with those at Tooborac (Singleton 1944) on the Cobaw massif, and at Bulla (Tattam 1925) shows that in these latter cordierite has developed to a greater degree, while andalusite is absent or rare. While these differences may be in part due to compositional variations in the parent sediments, it would seem that the retrograde activity at Big Hill is the more significant factor, particularly in accounting for the variations in cordierite development. In all three cases, temperatures and pressures were low during metamorphism, with conditions of the hornblende facies being attained only immediately adjacent to the contacts. The factors contributing to retrograde metamorphism at Big Hill are at present obscure but this should be clarified as the current work on the contact area of the whole batholith proceeds.

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Explanation to Figures

Fig. 1—Geological Map of the Big Hill Contact Area.

Fig. 2—Camera lucida drawings of spots and porphyroblasts in contact rocks, Big Hill.

i-iii Andalusite hornfels; transitional between zone of spotted saltes and zone of biotite andalusite hornfels.

iv-vi Andalusite hornfels; zone of biotite andalusite hornfels.

vii Andalusite hornfels; transitional between zone of biotite andalusite hornfels and zone of cordierite hornfels.

viii Superindividual of quartz; metaquartzite, zone of cordierite hornfels.

ix Cordierite hornfels.

x Metagreywacke; zone of cordierite hornfels.

(A andalusite, C cordierite, G graphite, SC sericite-cordierite, GI green isotropic material, GCS graphite-cordierite-sericite, GM green micaceous material, B biotite)